Harmonics

INTRODUCTION

In recent years, the modernisation of industrial processes and the sophistication of electrical machines and equipment have led to major developments in power electronics:

Semi-conductor-based systems (transistors, thyristors, etc.) designed for:

- Static power converters: AC/DC
- Rectifiers
- Inverters
- Frequency converters
- And many other multicycle or phase controlled devices.

These systems represent "non-linear" loads for electrical supplies. A "non-linear" load is a load for which the current consumption does not reflect the supply voltage (although the voltage of the source imposed on the load is sinusoidal, the current consumption is not sinusoidal).

Other "non-linear" loads are also present in electrical installations, in particular:

- Variable impedance loads, using electric arcs: arc furnaces, welding units, fluorescent tubes, discharge lamps, etc.
- Loads using strong magnetising currents: saturated transformers, inductors, etc.

The FOURIER decomposition (harmonic analysis) of the current consumption of a non-linear receiver shows:

- The fundamental, a sinusoidal term at the 50 Hz mains supply frequency
- The harmonics, sinusoidal terms whose frequencies are multiples of the fundamental frequency

According to the equation:

$$I_{rms} = \sqrt{I_1^2 + \sum_{h=2}^{n} I_h^2}$$

Σ : Sum of all the harmonic currents from harmonic 2 (50 Hz x 2) to the last harmonic n (50 Hz x n)

These harmonic currents circulate in the source. The harmonic impedances of the source then give rise to harmonic voltages, according to the equation:

$$Uh = Zh \times Ih$$

The harmonic currents give rise to most of the harmonic voltages causing the overall harmonic distortion of the supply voltage.

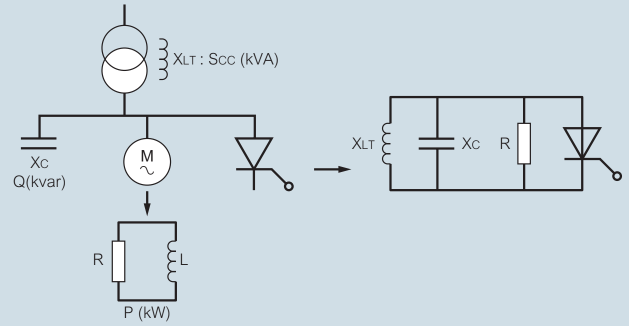
$$V_{rms} = \sqrt{U_1^2 + \sum_{h=2}^{n} U_h^2}$$

Note: The harmonic distortion of the voltage generated by construction defects in the windings of the alternators and transformers is generally negligible

Harmonics (continued)

EFFECT OF HARMONICS ON CAPACITORS

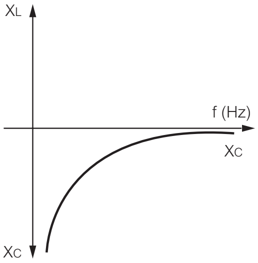
Schematic diagram **Equivalent diagram**



Note: As the inductance of the motor is much higher than that of the source, it becomes negligible in parallel configuration.

- Ssc (kVA): Source short-circuit power
- Q (kVAr): Capacitor bank power
- P (kW): Non-interfering load power

Reduction of the reactance of the capacitors



- The capacitor reactance

$$XC = \frac{1}{C.\,\omega} = \frac{1}{C.2.\pi.f}$$

is inversely proportional to the frequency, its ability to cancel out harmonic currents decreases significantly when the frequency increases.

• The higher the source short-circuit power (Ssc), the further the resonance frequency is from dangerous harmonic frequencies.
• The higher the power (P) of the non-polluting loads, the lower the harmonic current amplification factor.

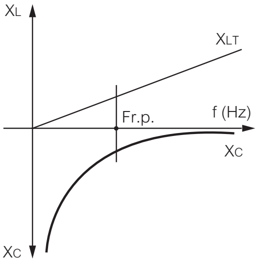
Main harmonic currents

The main harmonic currents present in electrical installations come from semi-conductor based systems. The theoretical rates of such systems are as follows:

- Harmonic 5 (250 Hz) - I5 - 20% I1*
- Harmonic 7 (350 Hz) - I7 - 14% I1*
- Harmonic 11 (550 Hz) - I11 - 9% I1*
- Harmonic 13 (650 Hz) - I13 - 8% I1 *

(* I1: Semi-conductor system current at 50 Hz)

Parallel resonance or anti-resonance between capacitors and source



- The reactance of the source X_{LT} is proportional to the frequency
- The reactance of the capacitors XC is inversely proportional to the frequency

At frequency Fr.p., there is parallel resonance or anti-resonance (as the two reactances are equal but opposite) and amplification (F.A.) of the harmonic currents in the capacitors and in the source (transformers) where:

$$Fr.p. = F\ supply\ \sqrt{\frac{Ssc}{Q}} \qquad F.A. = \sqrt{\frac{Ssc.\,Q}{P}}$$

PROTECTING CAPACITORS USING DETUNED REACTORS

For supplies with a high level of harmonic pollution, installing an detuned reactor, tuned in series with the capacitor, is the only effective protection.

The detuned reactor performs a dual role:
- Increasing the impedance of the capacitor in relation to the harmonic currents
- Shifting the parallel resonance frequency (Fr.p) of the source and the capacitor to below the main frequencies of the harmonic currents that are causing interference

- Fr.p.: Detuned reactor/capacitor/MV/LV transformer parallel resonance frequency

- Fr.s.: Detuned reactor/capacitor serial resonance frequency

- The most commonly used F.r.s values are:

- 50 Hz fundamental:	215 Hz (n=4.3) 190 Hz (n=3.8) 135 Hz (n=2.7)
- 60 Hz fundamental:	258 Hz (n=4.3) 228 Hz (n=3.8) 162 Hz (n=2.7)

- For frequencies below Fr.s., the reactor/capacitor system behaves like a capacitance and compensates the reactive energy.
- For frequencies above Fr.s., the reactor/capacitor system behaves like an inductance which, in parallel with the inductance XLT, prevents any risk of parallel resonance at frequencies above Fr.s. and in particular at the main harmonic frequencies.

HARMONIC FILTERS

For installations subject to a high level of harmonic pollution, the user may be faced with a dual requirement:
- To compensate for the reactive energy and protect the capacitors
- To reduce the harmonic distortion of the voltage to values that are acceptable and compatible with correct operation of most sensitive receivers (PLCs, industrial computers, capacitors, etc.)

For this, ALPES TECHNOLOGIES can offer "passive" harmonic filters. A "passive" harmonic filter is a combination of a capacitor and an inductance in series, for which each tuning frequency corresponds to the frequency of an unwanted harmonic voltage to be eliminated.

For this type of installation, ALPES TECHNOLOGIES offers the following services:
- Analysis of the mains supply on which the equipment is to be installed, with measurement of harmonic voltages and currents
- Computer simulation of the compatibility of the harmonic impedances of the supply and the various filters
- Calculation and definition of the various components of the filter
- Supply of capacitors, inductances, etc.
- Measurement of the efficiency of the system after installation on site